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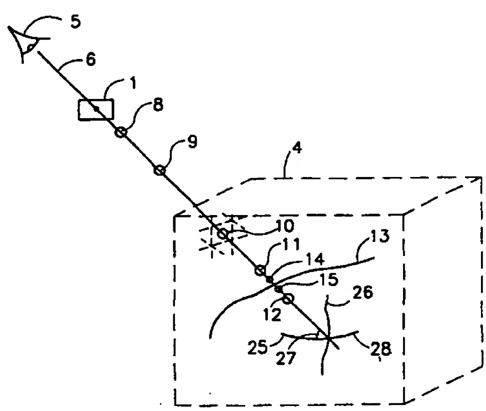

(57) Abstract

A method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space is disclosed. The method comprises steps of: a) initializing a virtual window of predetermined resolution pixels, and placing the virtual window in or near the voxel space; b) sparsely ray–casting a plurality of vectors from a predetermined vantage–point through the virtual window into the voxel space; and c) calculating a visualization–value at a series of positions along each vector. In a position ordering of steps from the vantage–point to the pixel, an accumulated transparency–value threshold is calculated. Values of proximate voxels are interpolated into an interpolated voxel value for each position. The interpolated voxel values are then transformed into a derived visualization–value and transparency value.

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A Method for Forming A Perspective Rendering from A Voxel Space

FIELD OF THE INVENTION

This invention relates to a method for forming a perspective rendering from a space of volume elements (voxels). More specifically, this invention relates to a family of algorithmic optimizations, which are useful in the forming of a perspective rendering from a voxel space.

BACKGROUND OF THE INVENTION

Many quantitative disciplines collect or generate multidimensional data. These disciplines include medical imaging applications such as CT or MRI; geophysical modeling, meteorological forecasting, scientific simulations, animation models, and the like. This multidimensional data is often stored and manipulated in the form of voxels. Voxels are volume elements in three (or more) dimensions; and are analogous to pixels (two dimensional picture elements).

Professionals often find it useful to be able to visualize some aspect of voxel data. The visualization requires transforming the voxel data, so that a cross-section, a projection, or another form of visualization can be realized on a two-dimensional display device. Numerous visualization techniques have been explored, and most are unfeasible for application; by reason of

computational complexities associated therewith. Nevertheless, there are certain basic desirable aspects of visualization standards for accepted renderings (representations).

The professional expects the visualization to facilitate elevated insights and to evoke increased understanding of the data. This is often accomplished by imposing (onto a rendering of the data) subjective criteria such as depth, shading, perspective, lighting, or shadowing; which are not necessarily generic to the data being rendered. For example, depth or shadow are not natural features of geophysical cross-sections; but may be helpful to the professional who is looking for ways to understand such a complex data set. Alternately, the professional may expect the visualization to be life-like (of realistic appearance).

The result of the professionals' rendering expectations and the computational complexity of accomplishing them has generated a cluttered convolution of rendering techniques. Some techniques have been developed which are specific to rendering certain data sets, while other techniques are seemingly more general in scope.

The nature of the prior art (of rendering a voxel space) can be better appreciated from studying US5201035, US5499323, US5594844, and from the prior art references cited therein. Furthermore, the order of complexity required for successful algorithmic optimization, in forming a perspective rendering from a voxel space, will thereby be appreciated.

The prior art is problematic and primarily application specific. Many overlapping combinations of more fundamental graphics algorithms are used in an attempt to simultaneously provide adequate rendering within algorithmic bounds that are economically and technically practical. Many examples of prior art methods are visually realistic but algorithmically heavy, and many other examples of the prior art are visually simplistic albeit

algorithmically feasible. Thus, there is a need in the art for rendering methods that are simultaneously visually realistic and algorithmically practical.

SUMMARY OF THE INVENTION

The present invention relates to a method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, the method including the steps of: **(a) initializing** a virtual window of predetermined resolution pixels, and placing the virtual window in or near the voxel space; **(b)** from a predetermined vantage-point, sparsely **ray-casting a** plurality of vectors through the virtual window into the voxel space; **(c) calculating** a visualization-value for each ray-cast vector not having an associated visualization-value, and therein for each position in a step dependent series of positions on the vector, and in a position ordering of steps from the vantage-point through the pixel, until an accumulated transparency-value threshold is reached or until a last available voxel intersecting with the vector is reached - whichever is sooner; by: *FIRSTLY **interpolating*** values of proximate voxels into an interpolated voxel value for the position; *SECONDLY **transforming*** the interpolated voxel value into a derived visualization-value and transparency value; and *THIRDLY,* using a predetermined selection rule, ***accumulating*** the derived visualization-value with a value presently stored in the corresponding pixel; and **(d)** until every pixel has an associated visualization-value, **selecting** a pixel (P) not yet having a visualization value, and *IF* substantially nearest pixels to the selected pixel (P) have computed visualization-values that are statistically homogenous, *THEN* **interpolating** a visualization-value from these substantially nearest pixels, and **assigning** the interpolated visualization-value to the selected pixel (P), *ELSE* ray-casting a vector

through the selected pixel (P) and assigning a visualization-value to the selected pixel (P) using *step (c)*.

The present invention provides a feasible method, both visually and algorithmically, for forming a high spatial resolution image perspective volume rendering from a low spatial resolution voxel space. The data, to be rendered into a visualization, is represented in a three-dimensional array of volume elements (voxels). Since the data stored in the voxels is not necessarily of a format, magnitude, or distribution useful for representation (e.g. on a display device such as a TV screen, a plotter, or the like), a transformation step is required in order to conform the data to a form that may be presented on a display device. These classes are used to transform one or more ranges of voxel values to doublets of a transparency-value and a representation-value (e.g. RGB for color, or gray-level, or the like). Recall that transparency-value and opacity-value are inverse quantifications of the same visualization aspect, so it is only by convenience of conceptualization that the present invention is described according to transparency-values or opacity-value.

According to the present invention, some interpolations are done before voxel value to visualization value transformations while other interpolations are done after these transformations. Interpolation is one of the key tools used to render a high-resolution image from a lower resolution representation. There are many functions that have proven useful for performing interpolations. Interpolation computationally solves for a value at a selected position from two or more neighboring positions. Interpolation functions may even consider all known locations having data-values to solve for a single location whose data-value is sought. In general, interpolation functions can be ordered; either in the same sense as polynomials, or according to a measure of algorithmic-computational complexity.

The tradeoff between low-order interpolations (e.g. linear), intermediate-order interpolations (e.g. cubic or spline), and higher-order interpolations directly affects the visual smoothness of appearance for images wherein interpolations have been used to synthetically create values for locations where no such values existed in the original data. Even for intermediate-order interpolations, there is a large algorithmic expense.

Therefore, in visualization applications, normally low-order interpolations are used for solving at all interpolation-requiring positions, except for a most critical sub-set of positions, such as positions close enough to the eye (e.g. foreground objects and not backgrounds). Furthermore, switching between different order interpolations is noticeable, and requires some secondary compensatory mechanism – especially if the criterion is proximity to the eye. These special considerations, for preserving an appearance of smoothness, are especially important because - often an object of the visualization is to maintain the clear resolution of distinct class boundaries (in the form of continuous iso-surfaces of voxel-values – as explained below).

In the context of the present invention:

(i) An "iso-surface" is a manifold in space in which the interpolation function of the voxel values is constant.

(ii) A "class" is the region in space in which the interpolation function assumes values that belong to a predefined interval.

Therefore, by the continuity of the interpolation function, it follows that a class is bounded by the iso-surface(s) corresponding to the edge(s) of the class(s) interval. It should be appreciated that in the context of the present invention the iso-surfaces that are "interesting" with respect to processing are the class bounding iso-surfaces.

Another significant aspect in rendering a visualization of data relates to lighting. There are two basic types of lighting: surface lighting and volume

lighting. Surface lighting occurs (is desired) when an external light source illuminates the surfaces of the classes. In the context of the preferred embodiment of the present invention, surface lighting originates from the same predetermined vantage-point as the "eye of the observer". By contrast, volume lighting derives from (is desired when) one or more voxels, in the "voxel space", are of themselves sources of illumination (radiant). In the context of several embodiments of the present invention, either surface lighting is used exclusively or volume lighting is used to complement surface lighting. According to one embodiment of the present invention, volume lighting is used exclusively.

Qualitatively, surface lighting values are proportional to the cosine of the angle formed between a vector connecting the eye and a point on an iso-surface and a normal to the iso-surface at that point; according to the embodiment where the light source is coterminous with the eye.

Qualitatively, volume lighting is proportional to the luminance (radiance) associated with one or more points in the voxel space, the distance between the luminescent point an the vantage-point (the eye), and the opacity (or equivalently but inversely - the transparency) of relevant voxels between the luminescent point an the vantage-point (the eye).

Qualitatively, opacity accumulates differently (between each voxel and the eye) according to the lighting model: surface, volume, or combination. In general, cumulative opacity represents the "Fraction of Light" ("*FoL*") (also referred to as "CT" – Cumulative Transparency) reaching the eye from a point in the voxel space; due to the light absorptive nature of the medium between the two (the eye and the point). Furthermore, it should be noted that the spatial precision necessary for successful rendering of surface lighting is significantly higher than that required for successful volume lighting.

According to the volume lighting model, luminescence (radiance) of the point is scaled (attenuated) by *FoL* by the time it reaches the eye.

According to the surface lighting model, luminescence (radiance) of the eye is scaled (attenuated) by *FoL*FoL* by the time it completes the path of from the eye to point and back to the eye. Furthermore, the surface normal direction used in the surface lighting calculation for iso-surfaces is determined using any one of many well-known analytic estimates for a gradient (of the interpolated iso-surface).

Accumulating a transparency value into a pixel is by updating the present transparency value for the pixel: $CT^{*}=T^{\text{current step size}}$ (see Figure 5); the present transparency value for the position on the vector exponentiated by the distance on the vector from the present position to the last position accumulated into the pixel; and the present transparency value for the position on the vector is a unit normalized transparency value.

A further significant aspect in "the process of volume rendering a visualization of data" relates to a well-known general technique called "ray-casting". Ray-casting substantially simulates a plurality of optical-information vectors that converge at the focal point of the eye. Equivalently, ray-casting simulates an algorithmic process wherein an accumulation of optical-information is organized with respect to a plurality of coterminous vectors; emanating outward from the eye. This algorithmic process enables a truncation of the vector (the cast ray) when the cumulative transparency of the traversed path becomes negligible.

According to the present invention, positions along the vector are selected for accumulating transparency values, and the step size between a present position and a next position is selected to be dependent on the opacity at the present position; albeit minimal and maximal step sizes limit the bounds of this proportionality. Furthermore, a change of class is detected by noting a change in opacity between two consecutive steps on a vector. Furthermore, according to the preferred embodiment of the present invention, in a region

traversed by the vector having a high transparency the step size is large and in a region traversed by the vector having a low transparency the step size is small.

According to the preferred embodiment of the present invention, volume lighting contributions are produced everywhere, whereas surface lighting contributions are only produced when crossing from a class of lower opacity to a class of higher opacity. This crossing is at a surface that is facing the eye (a front surface), while a crossing from higher to lower classes of opacity is a "hidden" surface (a back surface). For example, in a medical data context if a vector traverses through a mucus and encounters a tissue, then this encounter is a front surface; while the continuation of the vector may pass again into a mucus and this "second passing" is a back surface.

According to the criteria (for interpolation) for preserving an appearance of smoothness in the rendering of continuous iso-surfaces, a high order of spatial precision is necessary whenever a front surface's surface lighting contribution (to the cumulative opacity of the ray-cast vector) is to be calculated. Therefore, according to the preferred embodiment of the present invention, whenever a front surface is detected between two consecutive steps – a smaller step-size search is performed between the two "consecutive steps". This search is in order to achieve a higher order of spatial positioning for a point on the front surface intersecting with the vector; and also for the normal to this point on the iso-surface.

Given the special significance of these front surfaces to the rendering process, an additional layer of processing is introduced. This processing is intended to substantially prevent a situation from occurring wherein two consecutive steps skip over a front surface without detecting it. Continuing in the medical context example, suppose there is a membrane (or thin film of tissue or a bone fragment, etc) in the mucus, that is tangential to the vector. Because the membrane is surrounded by a transparent substance, the step size

risks "jumping over" the membrane without detecting the existence of the membrane.

Therefore according to the preferred embodiment of the present invention, an opacity-perturbation operation ("opacification") is performed. This opacification process is intended to prevent jumping over front surfaces without detecting their presence. In the opacification process, a table (or equation) is prepared from which an opacity value can be assigned to each voxel value. According to this table (or equation), opacity for each voxel value is taken as the maximum value of a predetermined neighborhood with respect to the original voxel value. Furthermore, step size on the vector is according to this table. Because this table effectively flags regions wherein there may be a front surface, the step size on the vector is always reduced whenever the vector is passing in the region of a front surface; even if there is no actual intersection between them. The perturbed values from the table (or equation) are NOT used in the accumulation of a cumulative opacity; and are only used as a conservative strategy for properly optimizing (better choosing of appropriate) step sizes so as to achieve a visually acceptable rendering.

According to the present invention, another aspect in the process of volume rendering relates to selective ray-casting. As can be appreciated from the forgoing aspects of processes involved in volume rendering, each actual vector that is cast (from the eye), and by virtue of which opacity data is accumulated, causes a measure of algorithmic complexity to be added into the cost of a volume rendering. Furthermore, it should be appreciated that an object of the present invention is to produce a high spatial resolution perspective rendering from a low spatial resolution voxel space.

Recalling that the central tradeoff in volume rendering is to provide a feasible method (both visually and algorithmically), the preferred embodiment of the present invention is directed to minimizing the extent to which actual

ray-casting is performed. According to a first approximation of this minimizing of ray-casting, a predetermined plurality of rays are cast.

According to one embodiment of the present invention, this predetermined plurality is distributed in a symmetric regular dispersion such that values for all intermediary rays can be interpolated from the cast rays without any additional ray-casting.

According to another embodiment of the present invention, intermediary rays are cast whenever the accumulated values from the heretofore cast rays are not statistically homogenous, and are otherwise interpolated.

According to a variation embodiment of the present invention, a first plurality of regularly distributed rays are cast; and in each region between these regularly cast rays a statistical homogeneity metric is computed. From these cast rays – *EITHER* values in the region are interpolated from neighboring cast-rays' values *OR* a next plurality of regularly distributed rays are cast in the region, and a next resolution metric is computed. This either-or processing is repeated *UNTIL* values for all rays in a desired spatial resolution of rays have associated values. This variation embodiment is an iterative zoom-in value filling process that uses, as appropriate, the previous embodiments of the present invention.

In general, the present invention can be defined as "A method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space". This method includes the four steps ("a" through "d") of:

(a) initializing a virtual window of predetermined resolution pixels, and placing the virtual window in or near the voxel space;

(b) from a predetermined vantage-point, sparsely **ray-casting** a plurality of vectors through the virtual window into the voxel space;

(c) (i) for each ray-cast vector not heretofore having an associated visualization-value,

(ii) and therein for each position in a step dependent series of positions on the vector,

(iii) and therein in a position ordering of from the vantage-point through the pixel,

(iv) and therein until an accumulated transparency-value threshold is reached or until a last available voxel intersecting with the vector is reached - whichever is sooner;

calculating a visualization-value **and storing** this visualization-value into the vector's corresponding pixel; by:

FIRSTLY ***interpolating*** values of proximate voxels into a interpolated voxel value for the position;

SECONDLY ***transforming*** the interpolated voxel value into a derived visualization-value and transparency value; and

THIRDLY, using a predetermined selection rule, ***accumulating*** the derived visualization-value with the value presently in the corresponding pixel; and

(d) until every pixel has an associated visualization-value, **selecting** a pixel (P) having the initialization from *step (a)*, and

IF substantially nearest pixels to the selected pixel (P) have computed visualization-values that are statistically homogenous,

THEN **interpolating** a visualization-value from these substantially nearest pixels, and **assigning** the interpolated visualization-value to the selected pixel (P),

ELSE **ray-casting** a vector through the selected pixel (P) and **assigning** a visualization-value to the selected pixel (P) using *step (c)*.

In relation to these four steps ("a" through "d" - above) and to the conditions and sub-steps therein, a few summary observations are worthy of note.

In step (a), according to the preferred embodiment of the present invention, the spatial resolution of the pixels is higher than that of a cross-section of voxels in the voxel space.

In step (b), if the vantage-point is far from the virtual window, then the rays cast through the virtual window will effectively be parallel each to another. Alternately, if the vantage-point is close to the virtual window, then the rays cast will effectively be approximating a divergent perspective; as subtended through the angle defined by the virtual window.

In step (c), all four conditions must be satisfied in order for the "calculating and storing" operation to be performed.

In step (c) condition (i), note that vectors are cast in step (b) and also in step (d) (at the "*ELSE*" sub-step).

In step (c) condition (ii), the "calculating and storing" are independently done for each position on the vector.

In step (c) condition (iii), there are two possible orderings in ray-casting. These orderings depend on whether the virtual window is between the voxel space and the vantage-point (as is the case for the present description); or equivalently whether the voxel space is between the vantage-point and the virtual window. The expression of "from the vantage-point through the pixel" is a convenient choice of nomenclature, which is not intended to exclude any equivalent logically consistent ordering. For example, if the virtual window were to be placed in the midst of the voxel space or if the vantage-point were to be placed in the midst of the voxel space, then there would be optional orderings such as:

- From the vantage-point to the virtual window.
- From the vantage-point through the virtual window.
- From the virtual window away from the vantage-point.
- From the virtual window to (or through) the vantage-point.
- From the end of the voxel space to the virtual window.
- From the end of the voxel space to the virtual window; and thereafter to (or through) the vantage-point.

In step (c) condition (iv), "whichever is sooner" relates to accumulating transparency until further accumulation will not effect the visualization or until there is no further data to effect the visualization. Furthermore, "transparency threshold" is a lower bound (or if stated equivalently – to an opacity threshold that is an upper bound).

In step (c) "FIRSTLY", there are numerous methods for accomplishing the interpolation.

In step (c) "SECONDLY", the transforming is according to the representation that is desired on a display device. Should the transforming be for interfacing with further image processing, then the transforming is according to the values appropriate to that processing.

In step (c) "THIRDLY", the accumulating is according to a lighting model, such as the surface lighting model, the volume lighting model, a combination of these two lighting models, a lighting model wherein the illumination source is not coterminous with the eye, or the like.

In step (d), it should be recognized that if the sparse ray-casting of step (b) is sufficient (as might be the case when implemented using parallel processing on the order of a processor per cast ray), then the supplemental ray-casting of the "ELSE" sub-step may never occur. This is not particularly problematic given the visual and algorithmic considerations motivating the method of the present invention.

It should also be appreciated that when there is a regular distribution of cast rays through the virtual window (in step (d) or even if done directly from step (b)) and when this distribution describes a spatial resolution in the virtual window that is higher than the spatial resolution of a cross section of the voxel space, then step (d) is expected to reduce to "selecting" and "interpolating" substantially without any further "ray-casting".

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of ray-casting geometry;

Figure 2 is a schematic mapping of a ray-casting ordering on a virtual window;

Figure 3 is a schematic diagram of a search on a ray for an iso-surface; **Figure 4** is a schematic diagram of a ray cast near an opacified iso-surface; **Figure 5** is a flowchart summarizing the basic logic process of the present method; and

Figure 6 is a schematic diagram of a computer system for forming a perspective rendering from a voxel space.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

The present invention relates to a method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space. (Turning to **Figure 1,** which is a schematic diagram of ray-casting geometry. This geometry is a typical geometry that is used in many embodiments of the present invention.) The method includes the four steps of:

(a) **Initializing** a virtual window (1) of predetermined resolution pixels (2) (3), and placing the virtual window in or near the voxel space (4). These pixels are logical storage elements corresponding to coordinates or regions of the virtual window. Normally, there is a simple and direct transformation from the geometry of the pixels of the virtual window to a display device (e.g. CRT, LCD, plotter, etc.).

(b) From a predetermined vantage-point (5), sparsely **ray-casting** a plurality of vectors (6) (7) through the virtual window into the voxel space. (Turning to **Figure 2,** which is a schematic mapping of a ray-casting ordering on a virtual window. For example first casting rays through the pixels marked "X", then casting rays

through the pixels marked "O", and finally casting rays or interpolating for the unmarked pixels – as in step (d) below.)

(c) (Turning now to **Figure 3**, which is a schematic diagram of a search on a ray for an iso-surface) For each ray-cast vector not heretofore having an associated visualization-value, and therein for each position in a step dependent series of positions on the vector (for example (8) (9) (10)), and therein in a position ordering of from the vantage-point through the pixel, and therein until an accumulated transparency-value threshold is reached or until a last available voxel intersecting with the vector is reached - whichever is sooner; **calculating** a visualization-value **and storing** this visualization-value into the vector's corresponding pixel; by: *FIRSTLY* ***interpolating*** values of proximate voxels into an interpolated voxel value for the position (for example from voxels in the neighborhood of position (10) on the vector); *SECONDLY* ***transforming*** the interpolated voxel value into a derived visualization-value and transparency value; and *THIRDLY,* using a predetermined selection rule, ***accumulating*** the derived visualization-value with the value presently in the corresponding pixel.

(d) Until every pixel has an associated visualization-value, **selecting** a pixel (P) having the initialization from *step (a)*, and *IF* substantially nearest pixels to the selected pixel (P) have computed visualization-values that are statistically homogenous, *THEN* **interpolating** a visualization-value from these substantially nearest pixels, and **assigning** the interpolated visualization-value to the selected pixel (P), *ELSE* **ray-casting** a vector through the selected

pixel (P) and assigning a visualization-value to the selected pixel (P) using *step (c)*. According to many voxel space-rendering applications, statistically homogenous is measured with respect to computed values stored in pixels or with respect to depth factors associated therewith. (In this context "depth factors" relate to the distance from the eye to the position on the ray in which the ray casting was terminated, due to reaching the transparency value threshold or reaching the end of the voxel space.)

According to the preferred embodiment of the method of the present invention, a next position in *step (c),* in the (transformed – see step (c) "SECONDLY") step-dependent series of positions along the vector, is selected using a variable step size from a present position; and the variable step size depends on an associated transparency for the transparency value of the present position. For most applications the step size increases with the transparency. Nevertheless there may be applications wherein the visualization of the transparent portions of the transformed voxel space is the important aspect of the rendering.

According to most embodiments of the present invention, the step size from the present position to the next position is never greater than a voxel cross-section for the voxel space. This maintains that the ultimate visual quality of the image (being captured in the pixels of the virtual window for eventual display on a display device of media) will not be less than the spatial resolution of the voxel space.

According to another embodiment of the present invention, a first present position (of the transformed step-dependent series of positions) along the vector is at the pixel corresponding to the vector. This is equivalent to disregarding any portion of the voxel space that is between the vantage-point

and the virtual window. According to the preferred embodiment, the first present position is at the eye (vantage point).

According to the preferred embodiment of the present invention, every next position (of the transformed step-dependent series of positions) is tested such that IF a (interpolated) voxel-value class iso-surface (as heretofore defined) has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is smaller than that of the present position, THEN at least one position between the present and next positions is examined to provide a higher spatial resolution positioning for the iso-surface. For example in the series of position on the cast ray in Figure 3, positions (11) and (12) are on opposite sides of an iso-surface (13). If the computed visualization value for position (12) is greater that that computed at position (11) then the front facing portion of the iso-surface has been traversed by the cast ray. This constitutes the detection of a class iso-surface.

Proceeding (for example with a search) back to test a position (14) and forward to a position (15) will increase the precision of the contribution by the iso-surface to the visualization value. Stated more formally, between firstly the at least one position and secondly either the present or next positions, a further at least one position is examined to provide a higher spatial resolution positioning for the iso-surface. Furthermore, further examinations of positions are performed until a predetermined precision is achieved in locating the detected iso-surface.

According to an alternate embodiment of the present invention, every next position (of the transformed step-dependent series of positions) is tested such that IF a class iso-surface has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is smaller than that of the present

position, THEN a position between the present and next positions is assigned as the location for the detected iso-surface.

Another optional enhancement which is applied to embodiments wherein iso-surfaces are detected relates to a visualization-value for the detected iso-surface being applied to the vector's associated pixel (by finding a normal (25) to the iso-surface (26) at the vector intersection point or equivalently) using a contiguous gradient to the vector iso-surface intersection location or from proximate elements of the intersection. This is applied by **calculating** a current surface lighting contribution to the cumulative visualization-value, and **accumulating** this surface lighting visulazation-value into the pixel. The surface lighting contribution is the visualization-value at the intersection position multiplied by the cosine of the angle (27) formed by the vector and the normal to the iso-surface at that location (28); and multiplying that by the cumulative transparency (accumulated in the associated pixel) squared.

According to the preferred embodiment of the present invention, an interpolated voxel value is calculated for a position along the vector from proximate voxels: using cubic interpolation for a position close to the vantage-point, or using linear interpolation for a position far from the vantage-point, or using a distance dependent graded mixture of cubic and linear interpolation for a position of a predetermined intermediate distance from the vantage-point. This is the preferred embodiment since the calculations are simple, the results are smooth and visually continuous, and the weighting of algorithmic efforts is high precision for close positions to the eye with a smooth decrease of precision as the position is further from the eye. Equivalently, any interpolation function, which traverses smoothly from high order precision for close positions to lower order precision for more distant position, is acceptable.

It should be appreciated that transparency values are unit normalized ("specific transparency"). In other words, the transparency values at each location denote the transparency corresponding to a "slab" of unit thickness. Usually the step size is not of a unit length. Therefore to calculate the transparency for the volume traversed by this step (interval), the unit normalized transparency value is exponentiated by the actual step size. Accumulating a transparency value into a pixel is by: multiplying the transparency value of the pixel by the transparency value for the interval.

According to the present invention, the predetermined selection rule of accumulating in step (c) includes a front surface detection and a surface-lighting. Furthermore, according to the preferred embodiment of the present invention, selecting a next position in the step dependent series of positions is coordinated with an opacification process.

According to the preferred embodiment of the present invention, class iso-surfaces are opacificied to facilitate a higher probability of detection. (Turning to **Figure 4,** which is a schematic diagram of a ray cast near an opacified iso-surface.) The opacification is performed by stretching the intervals defining the classes, where the more opaque classes take precedence. This has the effect that the iso-surfaces are shifted (inflated) from their actual location outward (to enclose less opaque regions). Iso-surfaces (16) has been opacified into expanded surface "buffers" bounded by iso-surface (17). On the cast ray (6), steps (20), (21) and (22) occur at regular intervals along the ray. At position (22) an opacity increase is detected because of the opacification. Therefore, the step size to (23) is reduced and the actual class iso-surface (16) is more likely to be detected. If the opacification were not performed, then the step after (22) would be at position (23A). Since position (23A) is in a region of transparency like that of position (21), the iso-surface would not have been detected without the opacification.

According to another embodiment of the present invention, the predetermined selection rule of accumulating in step (c) includes a volume-lighting (see Figure 5).

According to further embodiments of the present invention, implementation of the method will be accomplished in parallel. According to one embodiment, step (c) is executed in parallel, by processing for the "each ray-cast vector of any more than one ray-cast vectors requiring the processing of step (c). This may result in allocating a processor (for effecting the algorithm of step (c)) to each cast ray. According to another embodiment, step (d) is executed in parallel; by processing for the each ray-cast vector of any more than one ray-cast vectors requiring the processing of step (d). Likewise, this may result in allocating a processor (for effecting the algorithm of step (d)) to each cast ray.

According to the preferred embodiment of the present invention, in step (d), "selecting" of pixels is ordered for progressively generating nested levels of resolution at the virtual window. This selecting may be as described in Figure 2, or in quad-tree fashion, or by simulated zoom (or pan), or the like.

According to the preferred embodiment of the present invention, each transparency value is associated with a visualization-value for representation on a graphics display device. Furthermore, the representation is for associated color or gray levels.

In general the present invention is amenable for adaptation to numerous geometric permutations. According to the preferred embodiment of the present invention, a center surface region of the virtual window is placed perpendicular to an orientation vector from the vantage-point; and the orientation vector is an average of the plurality of vectors. Furthermore, the virtual window is planar. Alternately, the virtual window is curved or warped. Likewise the pixels are preferentially arranged in the virtual window as a

uniformly spaced rectangular grid. However alternatively, the pixels are arranged in the virtual window using circular coordinates, elliptic coordinates, or another conic projection of coordinates.

The method of the present invention, according to the preferred and the basic embodiments is directed to rendering the voxel space contains data derived from a Computer Tomographic (CT) scan, Magnetic Resonance Image (MRI), an ultrasound scan, a Nuclear Magnetic Resonance (NMR) scan, a geophysical survey, a meteorological survey, a scientific simulation, an animation from a model having more than two dimensions, or a set of simultaneous equations.

Accordingly, in the preferred embodiment of the present invention, the virtual window; having calculated, interpolated, or accumulated visualization-values stored in the pixels thereof; is rendered onto a display device.

(Turning now to **Figure 5 which** is a flowchart summarizing the basic logic process of the present method.) The follow notes are helpful in further understanding the detailed implementation of the present invention:

- "pass" denotes the iteration "phase", as measured from sparsely cast rays to higher resolution ray casting (or interpolation in the virtual window) to complete filling of the virtual window (as in step (d)) – (also see Figure 2).
- "pixel" denotes one or more data storage "values" corresponding to a location or region of the virtual window.
- "CT" denotes cumulative transparency.
- "(R, G, B)" denotes the red, green, and blue components of the visualization value.
- "T" denotes transparency value.
- "X += Y" denotes X is replaced with X+Y.
- "X *= Y" denotes X is replaced with X*Y.

The method of the present invention has been described with a certain degree of particularity with regard to ordering of steps, sub-steps, conditions, equivalents, and the like. This degree of particularity is not intended to limit the scope or spirit of the present invention, and is presented only for the purpose of conveying to those versed in the art such information as is necessary to properly appreciate the present invention and enabled embodiments thereof.

The present invention also relates to a computer system for forming a perspective rendering from a voxel space. (Turning now to **Figure 6** which is a schematic diagram of a computer system for forming a perspective rendering from a voxel space.) This system includes:

- a first memory media (61) wherein a voxel space is stored or represented;
- a computer processor (62) having data communications with the first memory media and with a second memory media, and the processor forms a virtual window of visualization pixels from a ray-casting into the voxel space, wherein the forming is according to the method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, substantially as herein-before defined and illustrated; and
- the second memory media (63) wherein the virtual window of visualization pixels is stored or represented.

The preferred embodiment of the present invention also relates to **generating** an index mapping of the homogeneity of the voxel space and to **consulting** this index mapping in order to decide if an interpolation computation is required – as part of the process of interpolating values of proximate voxels (step "c" *FIRSTLY*). For example, in order to further speed-up the process of ray-casting (with no penalty in image quality), an additional data-type is used, referred to as a BIT-VOLUME. In this data-type there is a single bit corresponding to each voxel. There are two variations in which a bit-volume may be used to facilitate ray-casting:

1st variation – Per class definition, the bit-volume is prepared (once) so that a value of 1 to a bit indicates the fact the a 4x4x4 cube of voxels (beginning with the voxel corresponding to that bit and extending to the positive sides of the x, y and z axes) belong to a single class.

During ray-case, when reaching a new position along the ray, the coordinates of the 4x4x4 cube of voxels needed for the cubic-interpolation of this position is calculated. Then, the value of the bit in the bit-volume corresponding to this cube (denoted by x) is queried.

a If $x = 0$ then the interpolation (cubic or linear, depending on the distance from the eye as detailed above) proceeds as usual.

b Else (if $x = 1$) then

i. If the previous position (the interpolated value of which was sought) also had $x = 1$, then the previously found interpolated value is also taken as the current interpolated value.

ii. Else (if the previous position had x = 0), the value of the interpolation is taken as an SINGLE voxel in the 4x4x4 cube of voxels.

Note that the interpolated value will be wrong. To see why this procedure works properly observe that for the algorithm to work properly (when visualization value is constant per class) it is sufficient for the used interpolated value to belong to the correct CLASS. Its exact value is inconsequential.

A sufficient condition that is easily met for which this correct-class-property holds in the above-described procedure is that the interpolated value always lies between the smallest and largest value used as input for the interpolation. Since a class is defined by an interval, and if all the inputs to the interpolation belong to the interval, then an interpolated value lying between the smallest and largest inputs must also belong to the interval and thus belong to the same class.

2nd variation – being similar in concept to the 1st variation – Per class definition, the bit-volume is initialized so that all bits are 0. In a similar fashion to the first variation, a value of 1 to a bit indicates that the 4x4x4 cube of voxels corresponding to that bit is known to belong to a single class. A value of 0 indicates that the class situation in the 4x4x4 cube is unknown or that they do not belong to a single class. Since at first nothing is known, the bit-volume is initialized to a constant 0.

During ray-cast, when reaching a new position along the ray, the coordinates of the 4x4x4 cube of voxels needed for the cubic-interpolation

of this position is calculated. Then, the value of the bit in the bit-volume corresponding to this cube (denoted by x) is queried.

a. If $x = 0$ then the interpolation (cubic or linear, depending on the distance from the eye as detailed above) proceeds as usual. If a cubic interpolation is performed, then the appropriate 4x4x4 cube of voxels used for the interpolation are checked and if found to belong to a single class, the corresponding bit in the bit-volume is set to 1. Note that since these voxels are used in the interpolation anyway, this check does not imply a big overhead.

b. If $x = 1$ then the algorithm proceeds exactly as in way 1.

CLAIMS:

1. A method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, the method comprising the steps of: **(a) initializing** a virtual window of predetermined resolution pixels, and placing the virtual window in or near the voxel space; **(b)** from a predetermined vantage-point, sparsely **ray-casting** a plurality of vectors through the virtual window into the voxel space; **(c) calculating** a visualization-value for each ray-cast vector not having an associated visualization-value, and therein for each position in a step dependent series of positions on the vector, and in a position ordering of steps from the vantage-point through the pixel, until an accumulated transparency-value threshold is reached or until a last available voxel intersecting with the vector is reached - whichever is sooner; by: *FIRSTLY* ***interpolating*** values of proximate voxels into an interpolated voxel value for the position; *SECONDLY* ***transforming*** the interpolated voxel value into a derived visualization-value and transparency value; and *THIRDLY,* using a predetermined selection rule, ***accumulating*** the derived visualization-value with a value presently stored in the corresponding pixel; and **(d)** until every pixel has an associated visualization-value, **selecting** a pixel (P) not yet having a visualization value, and *IF* substantially nearest pixels to the selected pixel (P) have computed visualization-values that are statistically homogenous, *THEN* **interpolating** a visualization-value from these substantially nearest pixels, and **assigning** the interpolated visualization-value to the selected pixel (P), *ELSE* **ray-casting** a vector through the selected pixel (P) and **assigning** a visualization-value to the selected pixel (P) using *step (c)*.

2. The method according to claim 1 wherein a next position in *step (c)*, in the step-dependent series of positions along the vector, is selected using a variable step size from a present position; and the variable step size depends on an associated transparency for the transparency value of said present position.

3. The method according to claim 2 wherein the step size from the present position to the next position is never greater than a voxel cross-section for the voxel space.

4. The method according to claim 2 wherein a first present position along the vector is at the pixel of the virtual window corresponding to said vector.

5. The method according to claim 2 wherein every next position is tested such that IF an interpolated class dependent iso-surface has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is greater than that of the present position, THEN at least one position between the present and next positions is examined to provide a higher spatial resolution positioning for the iso-surface.

6. The method according to claim 5 wherein, between firstly the at least one position and secondly either the present or next positions, a further at least one position is examined to provide a higher spatial resolution positioning for the iso-surface.

7. The method according to claim 6 wherein further examinations of positions are performed until a predetermined precision is achieved in locating the detected iso-surface.

8. The method according to claim 2 wherein every next position is tested such that IF a class dependent iso-surface has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is greater than

that of the present position, THEN a position between the present and next positions is assigned as the location for the detected iso-surface.

9. The method according to claim 5 or 8 wherein a visualization-value for the detected iso-surface is applied to the vector's associated pixel using a contiguous gradient to the vector iso-surface intersection location or from proximate elements of the intersection, by **calculating** a current surface lighting contribution to the cumulative visualization-value, and **accumulating** this surface lighting visualization-value into said pixel.

10. The method according to claim 1 wherein an interpolated voxel value is calculated for a position along the vector from proximate voxels: using cubic interpolation for a position close to the vantage-point, or using linear interpolation for a position far from the vantage-point, or using a distance dependent graded mixture of cubic and linear interpolation for a position of a predetermined intermediate distance from the vantage-point.

11. The method according to claim 1 wherein accumulating a transparency value into a pixel is by updating the present transparency value for the pixel: $CT^{*}=T^{\text{current step size}}$

12. The method according to claim 1 wherein step (c) is executed in parallel; by processing for said each ray-cast vector of any more than one ray-cast vectors requiring the processing of said step.

13. The method according to claim 1 wherein step (d) is executed in parallel; by processing for said each ray-cast vector of any more than one ray-cast vectors requiring the processing of said step.

14. The method according to claim 1 wherein each interpolated voxel value is associated with a visualization-value for representation on a graphics display device.

15. The method according to claim 14 wherein the representation is for associated color or gray level.

16. The method according to claim 1 wherein statistically homogenous is measured with respect to computed values stored in pixels or with respect to depth factors associated therewith.

17. The method according to claim 1 wherein a center surface region of the virtual window is placed perpendicular to an orientation vector from the vantage-point; and the orientation vector is an average of the plurality of vectors.

18. The method according to claim 1 wherein the virtual window is planar.

19. The method according to claim 1 wherein the virtual window is curved or warped.

20. The method according to claim 1 wherein the pixels are arranged in the virtual window as a uniformly spaced rectangular grid.

21. The method according to claim 1 wherein the pixels are arranged in the virtual window using circular coordinates, elliptic coordinates, or another conic projection of coordinates.

22. The method according to claim 1 wherein the voxel space contains data derived from a Computer Tomographic (CT) scan, Magnetic Resonance Image (MRI), an ultrasound scan, a Nuclear Magnetic Resonance (NMR) scan, a geophysical survey, a meteorological survey, a scientific simulation, an animation model having more than two dimensions, or a set of simultaneous equations.

23. The method according to claim 1 wherein, in step (d), "selecting" of pixels is ordered for progressively generating nested levels of resolution at the virtual window.

24. The method according to claim 1 wherein the virtual window; having calculated, interpolated, or accumulated visualization-values stored in the pixels thereof; is rendered onto a display device.

25. The method according to claim 1 wherein the predetermined selection rule of accumulating in step (c) includes a front surface detection and a surface-lighting.

26. The method according to claims 1 and 25 wherein selecting a next position in the step dependent series of positions is coordinated with an opacification process.

27. The method according to claim 1 wherein the predetermined selection rule of accumulating in step (c) includes a volume-lighting.

28. A computer system for forming a perspective rendering from a voxel space including:

(I) a first memory media wherein a voxel space is stored or represented;

(II) a computer processor having data communications with the first memory media and with a second memory media, and the processor forms a virtual window of visualization pixels from a ray-casting into the voxel space, wherein the forming is according to the method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, substantially as herein-before defined and illustrated; and

(III) the second memory media wherein the virtual window of visualization pixels is stored or represented.

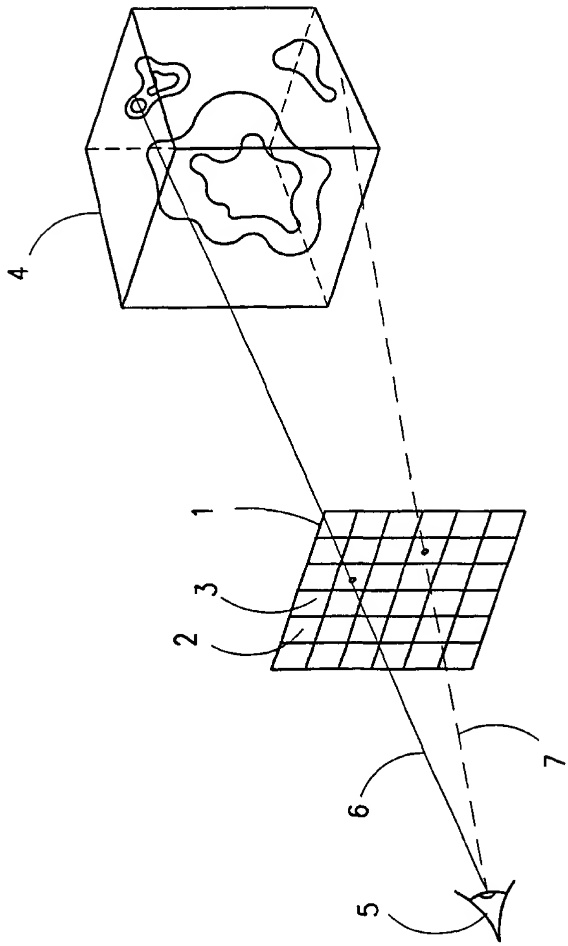


FIG.1

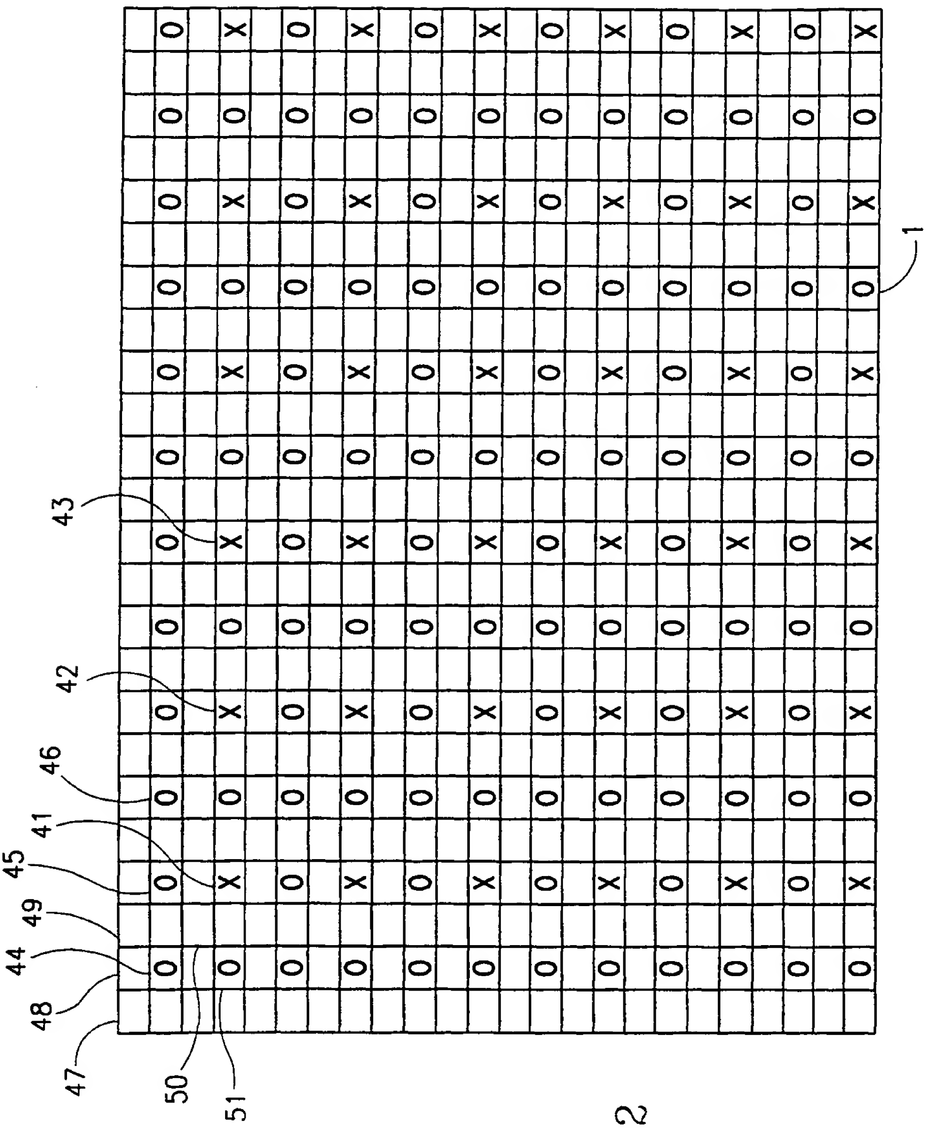


FIG.2

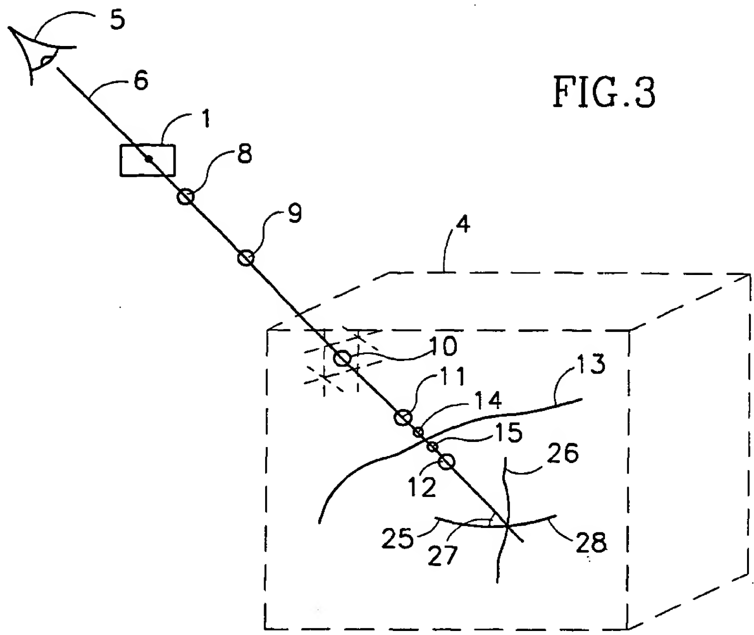


FIG.3

FIG.4

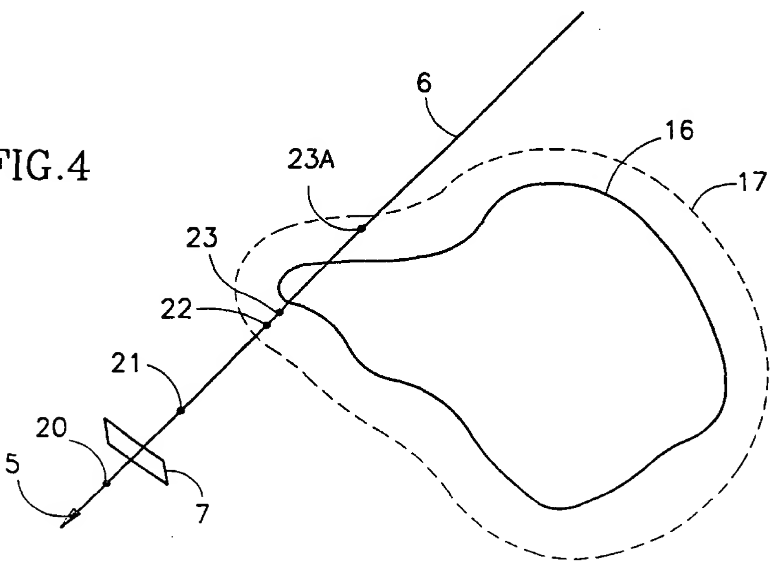


FIG.5A

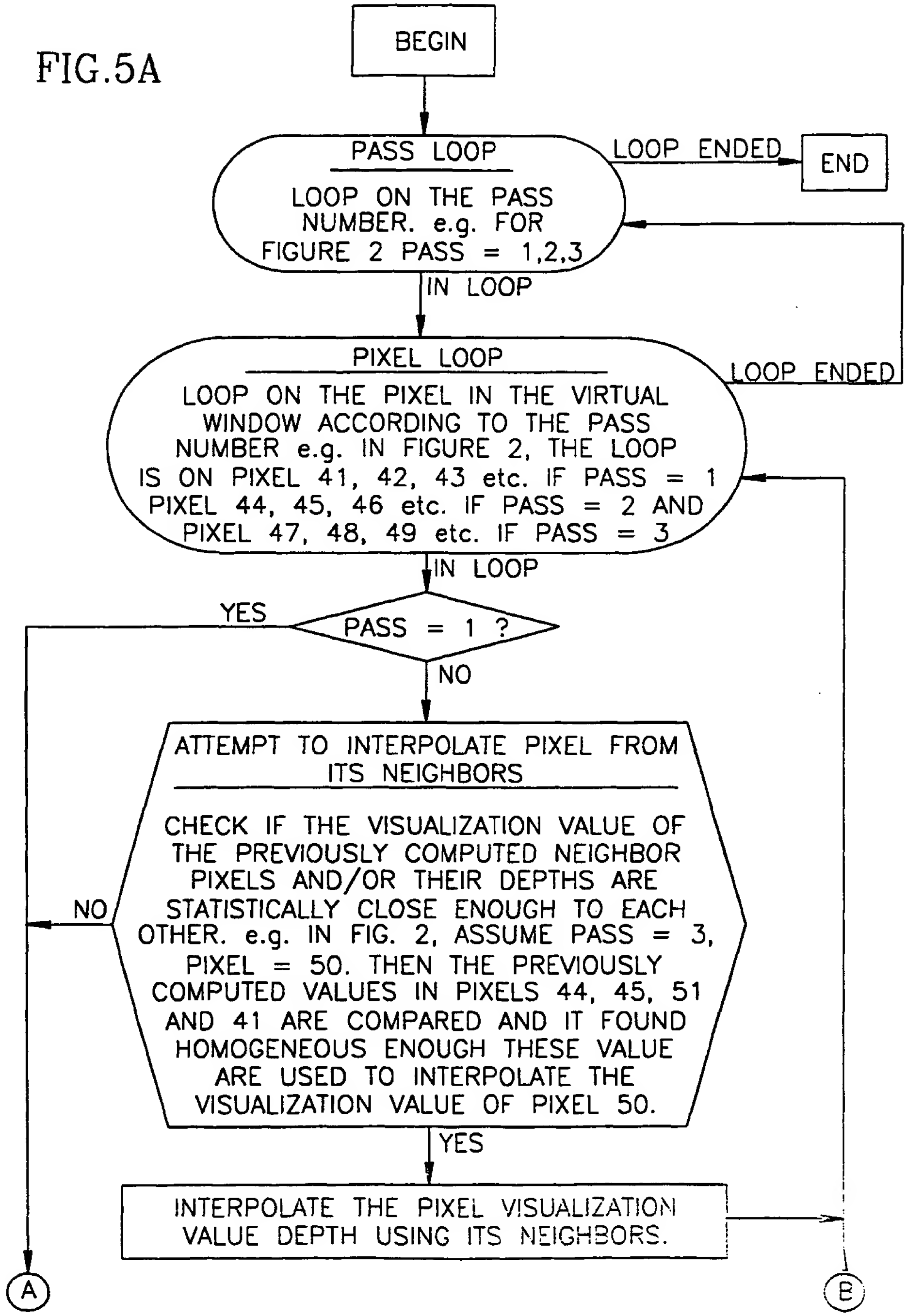
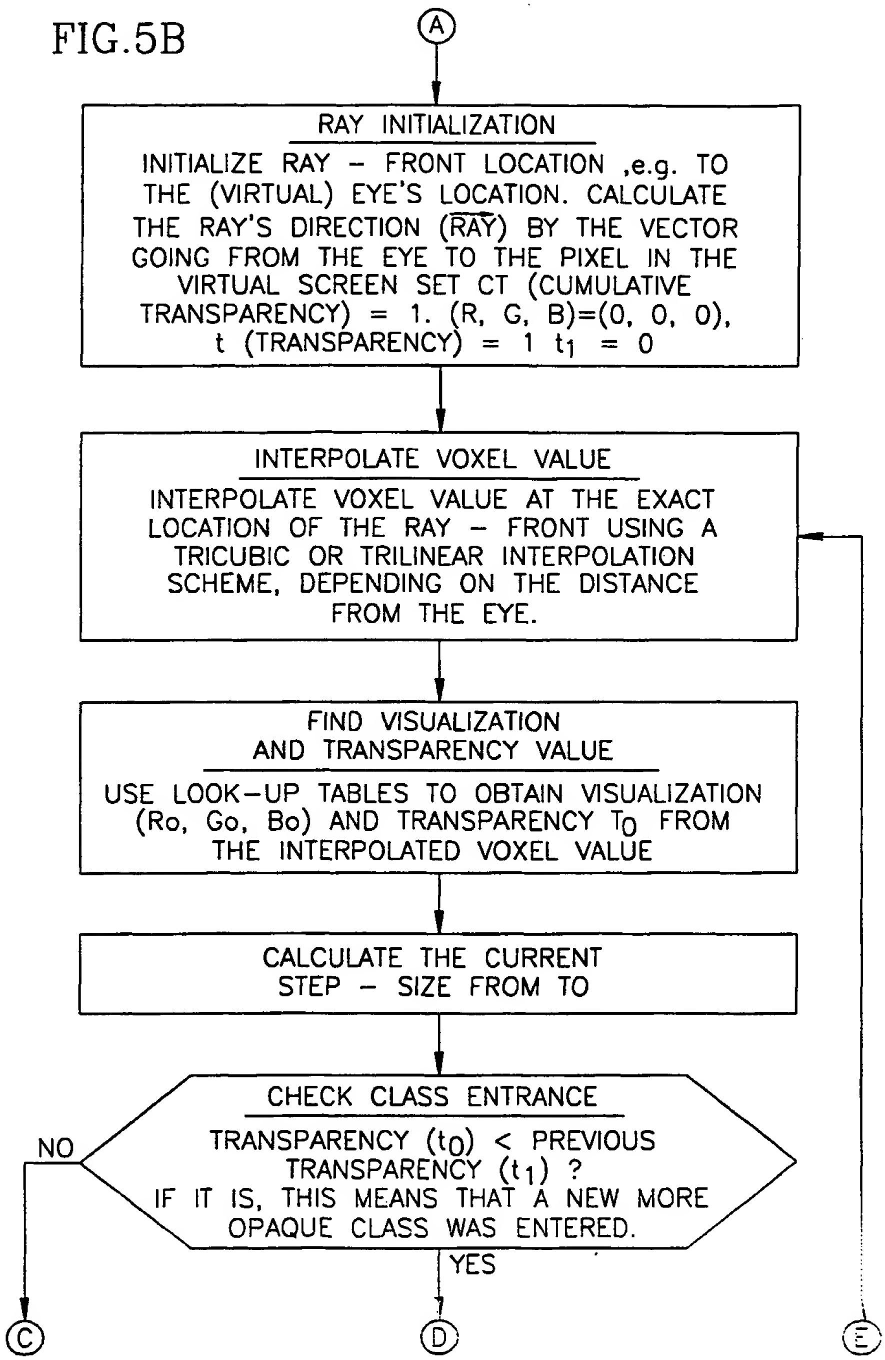

BEGIN
PASS LOOP
LOOP ON THE PASS NUMBER. e.g. FOR FIGURE 2 PASS = 1,2,3
LOOP ENDED
END
IN LOOP
PIXEL LOOP
LOOP ON THE PIXEL IN THE VIRTUAL WINDOW ACCORDING TO THE PASS NUMBER e.g. IN FIGURE 2, THE LOOP IS ON PIXEL 41, 42, 43 etc. IF PASS = 1 PIXEL 44, 45, 46 etc. IF PASS = 2 AND PIXEL 47, 48, 49 etc. IF PASS = 3
LOOP ENDED
IN LOOP
YES
PASS = 1 ?
NO
ATTEMPT TO INTERPOLATE PIXEL FROM ITS NEIGHBORS
CHECK IF THE VISUALIZATION VALUE OF THE PREVIOUSLY COMPUTED NEIGHBOR PIXELS AND/OR THEIR DEPTHS ARE STATISTICALLY CLOSE ENOUGH TO EACH OTHER. e.g. IN FIG. 2, ASSUME PASS = 3, PIXEL = 50. THEN THE PREVIOUSLY COMPUTED VALUES IN PIXELS 44, 45, 51 AND 41 ARE COMPARED AND IT FOUND HOMOGENEOUS ENOUGH THESE VALUE ARE USED TO INTERPOLATE THE VISUALIZATION VALUE OF PIXEL 50.
NO
YES
INTERPOLATE THE PIXEL VISUALIZATION VALUE DEPTH USING ITS NEIGHBORS.
A
B

FIG.5B


A
RAY INITIALIZATION
INITIALIZE RAY - FRONT LOCATION ,e.g. TO THE (VIRTUAL) EYE'S LOCATION. CALCULATE THE RAY'S DIRECTION ($\overline{RAY}$) BY THE VECTOR GOING FROM THE EYE TO THE PIXEL IN THE VIRTUAL SCREEN SET CT (CUMULATIVE TRANSPARENCY) = 1. (R, G, B)=(0, 0, 0), t (TRANSPARENCY) = 1 t_1 = 0
INTERPOLATE VOXEL VALUE
INTERPOLATE VOXEL VALUE AT THE EXACT LOCATION OF THE RAY - FRONT USING A TRICUBIC OR TRILINEAR INTERPOLATION SCHEME, DEPENDING ON THE DISTANCE FROM THE EYE.
FIND VISUALIZATION AND TRANSPARENCY VALUE
USE LOOK-UP TABLES TO OBTAIN VISUALIZATION (Ro, Go, Bo) AND TRANSPARENCY T_0 FROM THE INTERPOLATED VOXEL VALUE
CALCULATE THE CURRENT STEP - SIZE FROM TO
CHECK CLASS ENTRANCE
TRANSPARENCY (t_0) < PREVIOUS TRANSPARENCY (t_1) ?
IF IT IS, THIS MEANS THAT A NEW MORE OPAQUE CLASS WAS ENTERED.
NO
YES
C
D
E

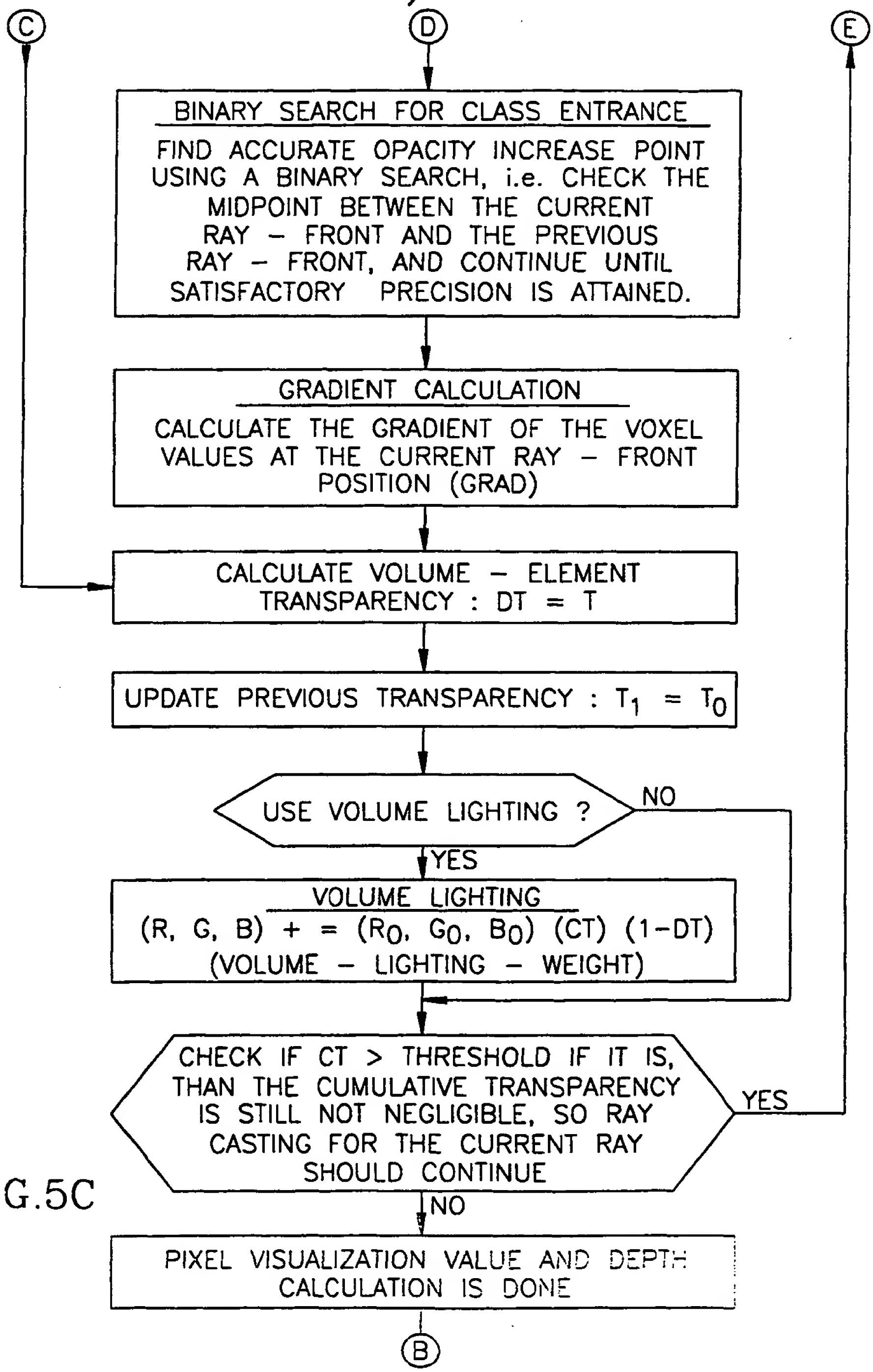

C
D
E
BINARY SEARCH FOR CLASS ENTRANCE
FIND ACCURATE OPACITY INCREASE POINT USING A BINARY SEARCH, i.e. CHECK THE MIDPOINT BETWEEN THE CURRENT RAY – FRONT AND THE PREVIOUS RAY – FRONT, AND CONTINUE UNTIL SATISFACTORY PRECISION IS ATTAINED.
GRADIENT CALCULATION
CALCULATE THE GRADIENT OF THE VOXEL VALUES AT THE CURRENT RAY – FRONT POSITION (GRAD)
CALCULATE VOLUME – ELEMENT TRANSPARENCY : DT = T
UPDATE PREVIOUS TRANSPARENCY : T_1 = T_0
USE VOLUME LIGHTING ?
NO
YES
VOLUME LIGHTING
(R, G, B) + = (R_0, G_0, B_0) (CT) (1–DT) (VOLUME – LIGHTING – WEIGHT)
CHECK IF CT > THRESHOLD IF IT IS, THAN THE CUMULATIVE TRANSPARENCY IS STILL NOT NEGLIGIBLE, SO RAY CASTING FOR THE CURRENT RAY SHOULD CONTINUE
YES
NO
PIXEL VISUALIZATION VALUE AND DEPTH CALCULATION IS DONE
B

FIG.5C

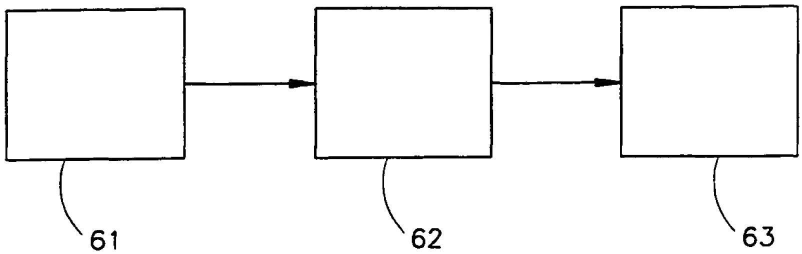


FIG.6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 99/00639

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T15/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 566 282 A (ZUIDERVELD KAREL JAN) 15 October 1996 (1996-10-15)	1,10, 14-16, 18,20, 22,24-28
	column 1, line 37 -column 3, line 55 column 7, line 51 -column 8, line 1	
A		2-28

X	FR 2 662 524 A (COATRIEUX JEAN LOUIS;DILLENSEGER JEAN LOUIS) 29 November 1991 (1991-11-29) page 3, line 31 -page 4, line 7 page 8, line 35 -page 10, line 6 page 11, line 32 - line 35 figures 2,3	1
Y		2-10,18, 20,21,23

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 March 2000	09/03/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Diallo, B

3

International Application No
PCT/IL 99/00639

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 98 47105 A (UNIV NEW YORK) 22 October 1998 (1998-10-22) claims 1,35,36; figures 3,10,18,19 page 4, line 21 -page 5, line 2 page 7, line 12 - line 24 page 20, line 27 -page 22, line 26 page 55, line 15 - line 31 ---	10,18, 20,21,23
Y	EP 0 362 123 A (VISUAL INFORMATION TECHNOLOGIE) 4 April 1990 (1990-04-04) column 9, line 20 - line 57; claim 4; figures 3,5 ---	2-9
A	US 5 381 518 A (DREBIN ROBERT A ET AL) 10 January 1995 (1995-01-10) abstract; claims 1,10; figure 4B column 2, line 39 -column 3, line 26 column 10, line 37 - line 42 ---	1,9,15, 25-27
A	US 5 557 711 A (MALZBENDER THOMAS) 17 September 1996 (1996-09-17) column 4, line 11 - line 61 column 6, line 56 -column 7, line 32 column 9, line 4 - line 5 ---	10-13, 18,20
A	US 5 694 530 A (GOTO YOSHIHIRO) 2 December 1997 (1997-12-02) figures 7,19,20,22 ---	16-20
A	US 5 568 811 A (OLSTAD BJ RN) 29 October 1996 (1996-10-29) column 3, line 59 - line 61; claims 7,8; figures 5,6 column 7, line 24 - line 43 ---	10,11
A	EP 0 442 682 A (IBM) 21 August 1991 (1991-08-21) abstract; claims 1,3,5,9 ---	1-28
A	US 5 555 352 A (LUCAS BRUCE D) 10 September 1996 (1996-09-10) column 6, line 25 - line 60; claims 1,12-14 -----	1-28

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 99/00639

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5566282 A	15-10-1996	EP 0612025 A	24-08-1994
		JP 6290276 A	18-10-1994
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		EP 0511537 A	04-11-1992
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PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

FENSTER, Paul
Fenster & Company Patent Attorneys,
P.O. Box 10256
49002 Petach Tikva
ISRAEL

PCT

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL PRELIMINARY
EXAMINATION REPORT
(PCT Rule 71.1)

Date of mailing *(day/month/year)* 26.02.2001	
Applicant's or agent's file reference 032/01394	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/IL99/00639	26/11/1999	27/11/1998

Applicant
ALGOTEC SYSTEMS LTD. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

   The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

   Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

   For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Atienza Vivancos, B Tel.+49 89 2399-7891

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 032/01394	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/IL99/00639	International filing date *(day/month/year)* 26/11/1999	Priority date *(day/month/year)* 27/11/1998
International Patent Classification (IPC) or national classification and IPC G06T15/20		
Applicant ALGOTEC SYSTEMS LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 6 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
27/06/2000	26.02.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Lubach, E Telephone No. +49 89 2399 8991

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IL99/00639

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

1-26 as originally filed

Claims, No.:

1-49 with telefax of 28/11/2000

Drawings, sheets:

1-7 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	
	No:	Claims	1,49
Inventive step (IS)	Yes:	Claims	
	No:	Claims	2-48
Industrial applicability (IA)	Yes:	Claims	1-49
	No:	Claims	

2. Citations and explanations
   see separate sheet

Ad V)

From Figure 1 and column 1, lines 47-61 of US-A-5 557 711 (D1) it is clear that perspective rendering according to features a), b), e) and f) of claim 1 is commonly known. It is further clear from D1 that if a ray passes from a first region to a second region effectively an interpolated value is calculated (see eq. (1) and (2) in column 4 of D1). It is clear from these equations that opacity and/or colour values are calculated for points along the rays. The examiner considers these to be visualisation values.
If these visualisation values are calculated where there is a transition between areas by nature these will be boundary visualisation values. Thus no novel or inventive features are apparent from Claim 1.
Since claim 49 is based on claim 1, similar comments apply here.

Dependent claims 2-48 appear to concern commonplace and obvious variations and implementation details of the subject-matter of claim 1, the conception and implementation of which all are deemed to be conducted routinely by those skilled in the art. These claims thus lack an inventive step.

REPLACED BY ART 34 AMDT

CLAIMS:

1. A method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, the method comprising the steps of: **(a) initializing** a virtual window of predetermined resolution pixels, and placing the virtual window in or near the voxel space; **(b)** from a predetermined vantage-point, sparsely **ray-casting** a plurality of vectors through the virtual window into the voxel space; **(c) calculating** a visualization-value for each ray-cast vector not having an associated visualization-value, and therein for each position in a step dependent series of positions on the vector, and in a position ordering of steps from the vantage-point through the pixel, until an accumulated transparency-value threshold is reached or until a last available voxel intersecting with the vector is reached - whichever is sooner; by: *FIRSTLY* ***interpolating*** values of proximate voxels into an interpolated voxel value for the position; *SECONDLY* ***transforming*** the interpolated voxel value into a derived visualization-value and transparency value; and *THIRDLY*, using a predetermined selection rule, ***accumulating*** the derived visualization-value with a value presently stored in the corresponding pixel; and **(d)** until every pixel has an associated visualization-value, **selecting** a pixel (P) not yet having a visualization value, and *IF* substantially nearest pixels to the selected pixel (P) have computed visualization-values that are statistically homogenous, *THEN* **interpolating** a visualization-value from these substantially nearest pixels, and **assigning** the interpolated visualization-value to the selected pixel (P), *ELSE* **ray-casting** a vector through the selected pixel (P) and **assigning** a visualization-value to the selected pixel (P) using *step (c)*.

2. The method according to claim 1 wherein a next position in *step (c)*, in the step-dependent series of positions along the vector, is selected using a variable step size from a present position; and the variable step size depends on an associated transparency for the transparency value of said present position.

3. The method according to claim 2 wherein the step size from the present position to the next position is never greater than a voxel cross-section for the voxel space.

4. The method according to claim 2 wherein a first present position along the vector is at the pixel of the virtual window corresponding to said vector.

5. The method according to claim 2 wherein every next position is tested such that IF an interpolated class dependent iso-surface has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is greater than that of the present position, THEN at least one position between the present and next positions is examined to provide a higher spatial resolution positioning for the iso-surface.

6. The method according to claim 5 wherein, between firstly the at least one position and secondly either the present or next positions, a further at least one position is examined to provide a higher spatial resolution positioning for the iso-surface.

7. The method according to claim 6 wherein further examinations of positions are performed until a predetermined precision is achieved in locating the detected iso-surface.

8. The method according to claim 2 wherein every next position is tested such that IF a class dependent iso-surface has been detected along the vector between the next position and the present position, by virtue of the indication that the transparency value of the next position is greater than

that of the present position, THEN a position between the present and next positions is assigned as the location for the detected iso-surface.

9. The method according to claim 5 or 8 wherein a visualization-value for the detected iso-surface is applied to the vector's associated pixel using a contiguous gradient to the vector iso-surface intersection location or from proximate elements of the intersection, by **calculating** a current surface lighting contribution to the cumulative visualization-value, and **accumulating** this surface lighting visualization-value into said pixel.

10. The method according to claim 1 wherein an interpolated voxel value is calculated for a position along the vector from proximate voxels: using cubic interpolation for a position close to the vantage-point, or using linear interpolation for a position far from the vantage-point, or using a distance dependent graded mixture of cubic and linear interpolation for a position of a predetermined intermediate distance from the vantage-point.

11. The method according to claim 1 wherein accumulating a transparency value into a pixel is by updating the present transparency value for the pixel: $CT^{*}=T^{\text{current step size}}$

12. The method according to claim 1 wherein step (c) is executed in parallel; by processing for said each ray-cast vector of any more than one ray-cast vectors requiring the processing of said step.

13. The method according to claim 1 wherein step (d) is executed in parallel; by processing for said each ray-cast vector of any more than one ray-cast vectors requiring the processing of said step.

14. The method according to claim 1 wherein each interpolated voxel value is associated with a visualization-value for representation on a graphics display device.

15. The method according to claim 14 wherein the representation is for associated color or gray level.

16. The method according to claim 1 wherein statistically homogenous is measured with respect to computed values stored in pixels or with respect to depth factors associated therewith.

17. The method according to claim 1 wherein a center surface region of the virtual window is placed perpendicular to an orientation vector from the vantage-point; and the orientation vector is an average of the plurality of vectors.

18. The method according to claim 1 wherein the virtual window is planar.

19. The method according to claim 1 wherein the virtual window is curved or warped.

20. The method according to claim 1 wherein the pixels are arranged in the virtual window as a uniformly spaced rectangular grid.

21. The method according to claim 1 wherein the pixels are arranged in the virtual window using circular coordinates, elliptic coordinates, or another conic projection of coordinates.

22. The method according to claim 1 wherein the voxel space contains data derived from a Computer Tomographic (CT) scan, Magnetic Resonance Image (MRI), an ultrasound scan, a Nuclear Magnetic Resonance (NMR) scan, a geophysical survey, a meteorological survey, a scientific simulation, an animation model having more than two dimensions, or a set of simultaneous equations.

23. The method according to claim 1 wherein, in step (d), "selecting" of pixels is ordered for progressively generating nested levels of resolution at the virtual window.

24. The method according to claim 1 wherein the virtual window; having calculated, interpolated, or accumulated visualization-values stored in the pixels thereof; is rendered onto a display device.

25. The method according to claim 1 wherein the predetermined selection rule of accumulating in step (c) includes a front surface detection and a surface-lighting.

26. The method according to claims 1 and 25 wherein selecting a next position in the step dependent series of positions is coordinated with an opacification process.

27. The method according to claim 1 wherein the predetermined selection rule of accumulating in step (c) includes a volume-lighting.

28. A computer system for forming a perspective rendering from a voxel space including:

(I) a first memory media wherein a voxel space is stored or represented;

(II) a computer processor having data communications with the first memory media and with a second memory media, and the processor forms a virtual window of visualization pixels from a ray-casting into the voxel space, wherein the forming is according to the method for forming a high spatial resolution perspective rendering from a low spatial resolution voxel space, substantially as herein-before defined and illustrated; and

(III) the second memory media wherein the virtual window of visualization pixels is stored or represented.

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:

REINHOLD COHN AND PARTNERS
P.O. Box 4060
61040 Tel-Aviv
ISRAEL

RECEIVED
12-03-2000
REINHOLD COHN & PARTNERS

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

	Date of mailing *(day/month/year)* 09/03/2000
Applicant's or agent's file reference 119155.0 MM	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/IL 99/00639	International filing date *(day/month/year)* 26/11/1999
Applicant ALGOTEC SYSTEMS LTD. et al.	

1. [X] The applicant is hereby notified that the international Search Report has been established and is transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

   When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

   Where? Directly to the International Bureau of WIPO
   34, chemin des Colombettes
   1211 Geneva 20, Switzerland
   Fascimile No.: (41-22) 740.14.35

   For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   [ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   [ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

   Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

   Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Aldo Vercio

Form PCT/ISA/220 (July 1998)

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule", and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international pbulication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped),whether

(i) the claim is unchanged;

(ii) the claim is cancelled;

(iii) the claim is new;

(iv) the claim replaces one or more claims as filed;

(v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]: "Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."

2. [Where originally there were 15 claims and after amendment of all claims there are 11]: "Claims 1 to 15 replaced by amended claims 1 to 11."

3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]: "Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or "Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."

4. [Where various kinds of amendments are made]: "Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international appplication is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the same time of filing the amendments with the International Bureau, also file a copy of such amendments with the International Preliminary Examining Authority (see Rule 62.2(a), first sentence).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, where upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see Volume II of the PCT Applicant's Guide.

BNSDOCID: <XSISA220NOENP4 I >

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 119155.0 MM	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/IL 99/00639	International filing date *(day/month/year)* 26/11/1999	(Earliest) Priority Date *(day/month/year)* 27/11/1998
Applicant ALGOTEC SYSTEMS LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.
   [ ] filed together with the international application in computer readable form.
   [ ] furnished subsequently to this Authority in written form.
   [ ] furnished subsequently to this Authority in computer readble form.
   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

Form PCT/ISA/210 (first sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 99/00639

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T15/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 566 282 A (ZUIDERVELD KAREL JAN) 15 October 1996 (1996-10-15)	1,10, 14-16, 18,20, 22,24-28
	column 1, line 37 -column 3, line 55 column 7, line 51 -column 8, line 1	
A		2-28

X	FR 2 662 524 A (COATRIEUX JEAN LOUIS;DILLENSEGER JEAN LOUIS) 29 November 1991 (1991-11-29) page 3, line 31 -page 4, line 7 page 8, line 35 -page 10, line 6 page 11, line 32 - line 35 figures 2,3	1
Y		2-10,18, 20,21,23

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 March 2000	09/03/2000

Name and mailing address of the ISA	Authorized officer
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